

Final Design Report: Infrasonic Wildfire Detection

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Senior Capstone Design

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ABSTRACT

Team FireSense (David DePaolis, Christopher Salcido, Nicholas Shipp, Luke Woods) have continued the work of designing an Infrasonic Wildfire Detection device throughout the 2021-2022 academic year by reducing the electronics size and cost, as well as developing a new payload delivery system. They achieved these goals by replacing the full-size development board with smaller packages and combining them onto a single printed circuit board, and by researching and prototyping a samara leaf (maple/helicopter seed) payload to protect the electronics during deployment. These changes allow for finer control over the layout and components of both the electronics and the payload, while reducing the cost and size of both aspects of the project. Team FireSense was able to evaluate and verify all components of the electronics function and were able to reliably repeat reduced velocity delivery of the payload.

The final size of the printed circuit board and components was 86.6140mm long by 45.7200mm wide by around 15mm thick, weighing 35.48g with a final cost of \$32 (36% reduction in cost per unit from previous years). The final payload assembly (electronics included) was 480.58mm long by 158.74mm wide by 19.35mm tall in the shape of a samara leaf, transitioning to autorotation flight after 25ft, and falling with an angle of attack of 29.3° at a velocity of 1.83m/s.

BACKGROUND

As the past several years have shown us, wildfires have become an increasingly prevalent threat to homes and businesses across the country. However, surveying expansive wilderness areas is impractical, and current detection methods are constrained to sight and smell of smoke (from Firewatch towers on the ground) or from a combination of visible and infrared imaging from satellites. Research at the University of Idaho in the College of Natural Resources revealed that wildfires reliably give off a characteristic low-frequency signal (infrasound, below 20Hz) that is not often found in nature.

To augment the current wildfire detection methods, previous capstone teams at the University of Idaho have constructed an Infrasonic Wildfire Detection sensor. The first year identified all the necessary components needed to create this sensor and designed a low-pass filter to isolate the infrasound so that an inexpensive microphone could be used for signal acquisition. The second team (2020-2021) developed a point-to-point mesh network communications system, so that we can deploy a network of sensors over an area and have them communicate with each other. This would be used for relaying the information that one node receives back to a central location where the data could be processed and acted upon.

This technology could be deployed over a large area of land, which may be at a heightened risk for wildfires, and remain there listening for wildfires through the course of a fire season. This would serve as an additional method of detection and could increase the speed at which existing fire control infrastructure can respond to a natural disaster.

PROBLEM DEFINITION

Stanley Solutions presented the project to us with the goal of finding and developing an aspect of the project we would be enthusiastic about improving (with slight emphasis on payload

drop testing). After reviewing the past teams' work on the Infrasonic Wildfire Detection device, FireSense identified six areas that could be improved: Troubleshoot PCB (microphone signal acquisition), Condense Circuitry, Battery/Life and Power, Networking Communications, Signal Identification/Analysis, and Payload Design/Delivery.

FireSense decided that the aspects most in need of improvement were the size and the cost of the electronics and developing a new payload delivery system. The sensor electronics handed off to team FireSense were a prefabricated development board (~\$50/unit) with excess components and a large filter attached. The payload handed off to the team was a robust PVC tube enclosure with a prototype cloth parachute.

The payload is required to perform all the following:

- Survive deployment
- Establish a dynamic mesh network
- Collect infrasonic signals
- Report information to a central location

The current electronics system enclosure fits within the following:

- Length < 7in
- Diameter < 3in
- Volume < 50in²

The final electronics system enclosure specs will be equal to 50% or smaller than the current payload size. The wing portion of the payload will be considered different from the electronics system enclosure and will be required to fit within the same volume listed above.

The cost to build a proof-of-concept prototype shall not exceed a value of \$50. The goal for the final product will be to not exceed \$25 per payload device.

The following are the major Project Milestones:

1. PRD, Value Proposition	September 23 rd , 2021
2. Project Schedule, Budget, DVP	October 7 th , 2021
3. Snapshot Day 1	October 12 th , 2021
4. Concept Design Review	November 12 th , 2021
5. Snapshot Day 2	December 3 rd , 2021
6. Engineering Release Review	February 18 th , 2022
7. Design EXPO	April 28-29 th , 2022

PROJECT PLAN

Team Roles and Responsibilities

Team FireSense consisted of four members:

- David DePaolis – Electrical Engineering, Physics
- Christopher Salcido – Mechanical Engineering
- Nicholas Shipp – Computer Engineering

- Luke Woods – Mechanical Engineering

With the two paths for the project chosen (reduce PCB size/cost, and further develop payload delivery system), we split into two teams to develop these solutions in parallel.

DePaolis and Shipp would identify the necessary components for the function of the sensor according to the code that had been developed the year prior, removing the non-essential components, and condensing all the electronics into one PCB. DePaolis reviewed the first team's work on the filter system, identified surface mount technology alternatives to through hole parts, and performed rudimentary power testing of the PCB. Shipp identified the required electronic components and designed all versions of the PCB, as well as manufactured the test/prototype circuit boards.

Salcido and Woods would research, design, and prototype a samara leaf (maple/helicopter seed) inspired payload delivery system to house and protect the electronics during the initial drop and deployment in the field. Salcido designed the battery holders that were implemented into the body of the payload, assembled all testing models, and performed drop testing and impact analysis. Woods designed all versions of the full payload, manufactured all constituent components of the payload, performed drop testing and impact analysis, and finalized all team presentations and reports.

Salcido conducted oversight of the team's budget. Both Salcido and Woods created Team Agendas. All team members took Meeting Minutes throughout the year.

Project Schedule

The following figure illustrates a condensed version of the team's project schedule. A fully detailed version of the schedule can be found in the appendix.

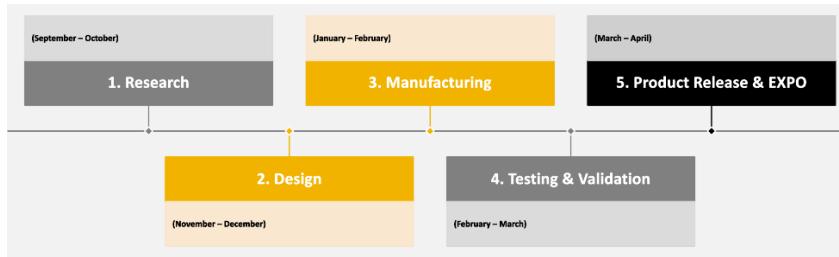


Figure 1: Condensed Project Schedule, Main Sections and Dates

CONCEPTS CONSIDERED

PCB Redesign

DePaolis and Shipp revisited the electronics design from previous teams and found several areas to further reduce the size, cost, and system power consumption with the project's long-term goal of being mass produced in mind. For size and cost, the focus was re-selection of essential components only, use of surface mount equivalents for through-hole components, and PCB layout

optimizations. For system power, the focus was on lighter and more environmentally friendly battery alternatives.

Size/Cost Reduction

Previous teams used a bulky and expensive prefabricated development board. While this was beneficial for proof-of-concept work, further size and cost reductions needed to be made. Fire Sense considered stripping the electronic components to the bare minimum to get away from the development board. In doing so the system could then be moved onto a single PCB. Surface mount components (SMT) provide an attractive alternative to through hole components (THT) because of their reduced size, and only interacting with a single layer of the PCB. However, it should be noted that SMT components are more difficult to handle and verify with testing once soldered.

PCB layout optimizations were a constant consideration for Fire Sense throughout the iterative design process. Reducing the size of the electronics in turn reduces the size of the entire payload, as the wing is proportional in size to that of the electronics. When choosing design suites, there were two main options, both equally valid: Autodesk Eagle or KiCad. When choosing manufacturers, two main options present themselves: Commercial Manufacturers or the In-House PCB Shop. Commercial Manufacturers have the benefit of being able to reliably produce boards with fine trace width/spacing, including a solder mask and silkscreen, but take a considerable amount of time to be delivered. The in-house PCB shop on campus is limited to two copper layers with no solder mask or silkscreen, and trace width/spacing no smaller than 0.5mm. The turn-around time is only a couple of days, however, which lends itself to rapid prototyping. It should also be noted that plated through holes must be requested ahead of time and take an extra day to manufacture but simplifies soldering of components and increases the reliability of the circuit.

System Power

The development board used by previous teams sported a battery holder for a Lithium-Ion 18650 cell. While this is a common and low-cost option, it is large and by no means the most environmentally friendly option. Fire Sense researched several battery types (Liquid-Air, Lithium-Air, and Zinc-Air) prioritizing options that were small, low weight, and had an inert chemical makeup.

Further considerations were also proposed to extend the battery life of the system. Additional battery cells can be added to a modular power bank to increase capacity, but weight distribution of the payload will need to be re-considered. Additionally, integrating a solar panel element into the wing of the payload could be used to recoup some of the power consumed during normal operation.

Payload Design/Delivery

Salcido and Woods reviewed the progress past teams had made on the drop deployment for the payload and found there was ample room for further development. They reviewed different deployment methods and determined the following four solution paths: Parachute Deployment, Blunt Force Delivery, Autorotation Motors, Samara Leaf.

Parachute Deployment

Fire Sense could have reduced the velocity of payload by using the Drag equation to design a parachute.

$$D = \frac{1}{2} \cdot A_p \cdot \rho \cdot V^2$$

Drag Equation

Where D is drag, A_p is the area of the desired parachute design, ρ is air density, and V is velocity. To find the mathematical effectiveness of different parachute designs before conducting drop testing, a velocity would be found depending on the weight of the payload and the area of the parachute. Parachutes come in three basic shapes, each with different flight characteristics.

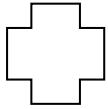


Figure 2: Cross Parachute



Figure 3: Square Parachute

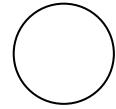


Figure 4: Circle Parachute

The cross shape is easy to build, it has a low drag coefficient, and it is more stable as it falls. The square parachute is the easiest to build, it has the most intermediate drag coefficient, but it is the least stable as it falls. The circle is slightly more difficult to build, it has the highest drag coefficient, and is the most unstable as it falls.

There were drawbacks of the parachute design. When dropped into the wilderness without the guarantee of support from technicians, the parachutes could get caught in trees which would be advantageous for signal propagation, but they could interfere with the local environment. Parachutes also have far more points of failure than the following options, as well as requiring more assembly and care when packing.

Blunt Force Delivery

The payload would need to be robust enough that it does not break the internal components as it impacts the ground. One idea for accounting for this is to cushion the components inside the payload to mitigate the force of the impact. A payload that falls at terminal velocity must also be directed aerodynamically to land in a desired orientation (antenna and microphone facing up). Falling at terminal velocity would also create a hazard for wildlife that may happen to be underneath.

Autorotation

Rotor blades can spin from the relative wind coming from under them, as opposed to from a motor, and continue to generate lift. This concept lends itself to a falling payload that needs to reduce its velocity to protect its components. The main concern team FireSense had was the moving parts. Because the rotors must be able to spin freely, this introduced a major point of failure for the payload. Another consideration that would have to be made for this design is

reducing the amount of friction between the payload body and the rotor blades. This could be avoided by fixing the blades to the body and allowing the whole payload to rotate, which leads us into the final solution we researched, the samara leaf.

Samara Leaf

A samara leaf (or maple/helicopter seed) functions utilizing the same principle of autorotation as described above. As the seeds fall, part of the wing catches the wind and forces the wing to begin spinning. The spinning motion causes the rest of the wind to generate lift for the seed. This reduces its terminal velocity by converting part of it into rotational velocity and lift. The advantages of this type of payload are numerous.

Team Fire Sense's research showed that the maple seed (and its flight characteristics) can be reliably reproduced in a lab setting (Wind Dispersal of Natural and Biomimetic Maple Samaras). The seed itself is also "stable against wind disturbance and is insensitive to initial conditions" (IOP Science) because it will always rotate to enter dart-mode before transitioning to autorotation (Wind Dispersal of Natural and Biomimetic Maple Samaras). The seeds are also chiral (IOP Science), meaning they will always land with one side facing up, which is ideal when accounting for the placement of the antenna and microphone. The most advantageous factor of the samara leaf is that it is a single mechanical body, reducing the points of failure and allowing for simpler manufacturing.

CONCEPT SELECTION

Electronics Design

DePaolis and Shipp decided to pursue several of the PCB redesign considerations listed above. To move the electronics onto a single PCB, components were reselected so that only necessary components remained. These components included: an ESP32 development board for system processing, a GPS chip for node location, a transceiver for message relaying, a voltage regulator for a stable power rail, and passive components for signal filtering. Links to specific component datasheets are included in the appendix at the end of this report.

When designing the PCB layout, Shipp used KiCad (v6.0) as this was our project sponsor's (Joe Stanley) preferred design suite. The program is intuitive and well documented online, with several footprint libraries included. SnapEDA also proved useful for sourcing PCB footprints for components not included in KiCad's native libraries. To facilitate multiple prototypes, the In-House PCB shop was used over other Commercial Manufacturers as the turn-around time is much quicker on campus.

After researching the batteries used previously, and several other battery alternatives, the decision was made to proceed using Zi-Air 675 cells. These batteries provide us with marginally improved energy density as compared to the previously used Li-Ion cells, while also greatly reducing the size and weight of the power system. Zi-Air cells also have an inert chemical makeup which helps to minimize the environmental impact of our payloads.

Payload Design/Delivery

Salcido and Woods pursued the benefits of the samara leaf method of delivery, sighting its straightforward design and rapid reproducibility, both in manufacturing and simulation. Modeling both the Blunt Force Delivery Method and the Parachute method had been produced by the previous year's team in their initial payload design. To investigate the samara leaf, Salcido assembled a balsa wood and tissue paper model at the conclusion of Fall Semester 2021 to demonstrate the design without rapid manufacturing.

After reviewing the previous team's payload work and considering the benefits of each design, the decision was made to develop rapid prototypes of the samara leaf.

Payload Material Selection

A material selection index (Materials Selection in Mechanical Design) was developed with the help of Dr. Matthew Swenson to judge materials based on their performance characteristics. A material index is built considering an object's geometry and integrating in an equation that includes the material's desired quality (strength, density, etc.). Dr Swenson and the book recommended the following Strength over Density index for picking materials for the composite design of a wing because it would find materials maximizing strength and minimizing density.

$$M = \frac{\sigma^2}{\rho}$$

Figure 5: Strength over Density calculation

Once the Material Index was found, it was applied to a material selection graph representing Strength over density. It was decided to model physical samara models out of PLA and wood because both had similar strength to density ratios for keeping their shape during moments of light force impact but will not be so heavy that they would affect flight characteristics unfavorably.

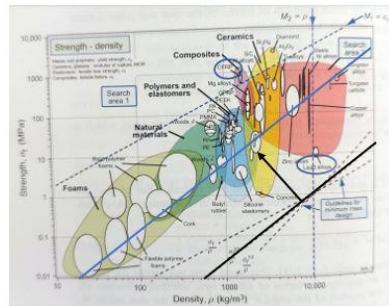


Figure 6: Material Index for Strength over density

SYSTEM ARCHITECTURE

Electronics Design

The electronics system was comprised of three main parts: the battery array, the signal filter, and the communications system.

The battery array needed to supply a consistent 3.3V rail to the rest of the system; this was achieved with a set of 3 Zi-Air cells that were placed in series and connected to a voltage regulator. The regulator was required due to the variation in the cells' nominal voltage levels (1.45V down to 1.15V per cell) with typical discharge. This modular design allowed for additional sets of battery cells to be added in parallel, thereby increasing the overall capacity of the power bank. Our design currently includes two sets of battery cells (6 individual Zi-Air cells).

The signal filter needed to listen to its surroundings and identify if a nearby wildfire was emitting its characteristic low-frequency signals. To achieve this, a simple 2-pin electret microphone was employed in tandem with a low-pass Chebyshev filter to detect sounds from the environment and sharply attenuate signals above the infrasonic focus. The filter was configured with typical RC filter passive components and op-amp ICs (LM358s) to boost the mic input, validate the signal, and boost the output to readable voltage levels. Transitioning from a through-hole technology solution to a primarily surface-mount configuration permitted significant size reductions which are exhibited in the figures below.

The processing/transmission system is needed to create and send messages when the signal filter detects a wildfire and relay messages from other nodes that are also transmitting. To achieve end, the ESP32 development board will acquire the node location from the GPS chip and process it to create an initialization message to be sent via the on-board transceiver through the mesh network. Nodes on the mesh network will carry this information to a central location/master node wherein the signal could be processed and displayed to the operator.

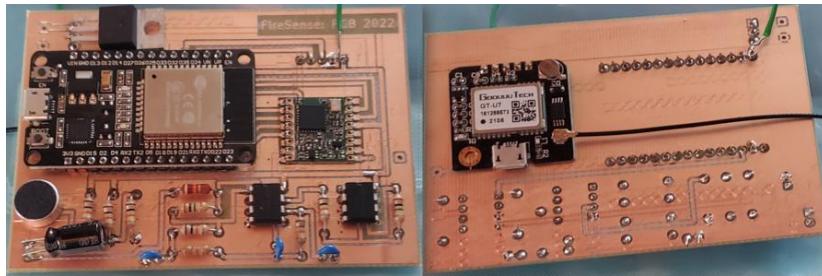


Figure 7: PCB Version 1 Including Through Hole Components

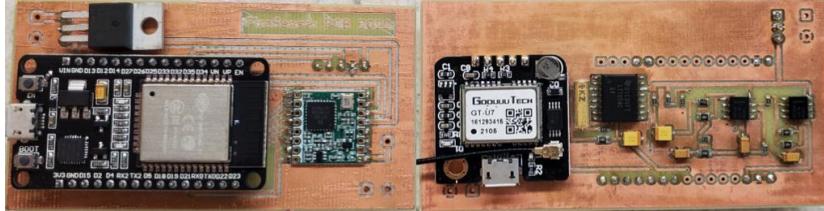


Figure 8: PCB Version 2 Including Surface Mount Components

Payload Design

The samara leaf has two distinctive features: a thick and heavy nut, and a large thin wing. The large nut lends itself perfectly to housing all the electrical components for the sensor, while the large thin wing can be manufactured around the size of the nut to achieve the desired flight characteristics. In addition to the rationale of the previous section for the composite payload materials selected, the use of PLA plastic and wood for manufacturing the main components allows us great flexibility in the design.

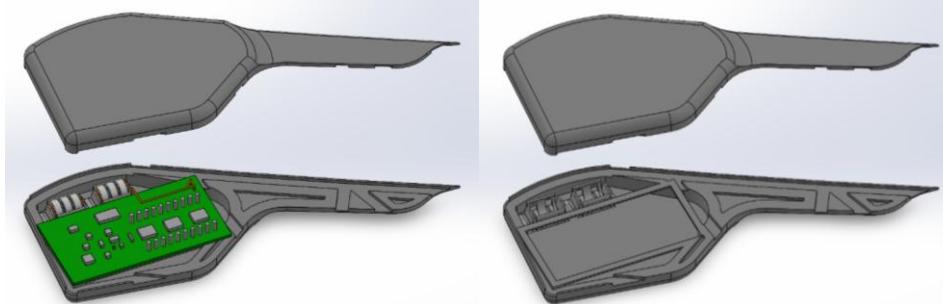


Figure 9: Images of Samara Payload Housing with and without components

Team FireSense utilized 3D printing of the PLA plastic to manufacture the nut of the payload. This allowed them to customize the design of the payload nut housing to fit exactly around the components included, while maintaining the ability to easily alter the design as they continued their work. Manufacturing the housing using 3D printing provided a much faster turnaround time than machining would, providing the advantage of being able to manufacture and evaluate prototypes early. The payload housing is dimensioned to fit tightly around the condensed PCB while maintaining the shape of the samara leaf found in nature. The interior of the housing is primarily filled by the condensed PCB and its components, with supports to hold it in place during deployment. The payload nut housing is 116.11mm by 91.79mm by 19.35mm with a wall thickness between 1 and 6.5mm at its thinnest and thickest. The tail extends out an additional 102.21mm, is on average 21.23mm wide while tapering in and out and is 3.28mm thick. There is an inlay set around the outer edge of the payload with the exact depth and contouring of the wing skeleton to hold it in place.

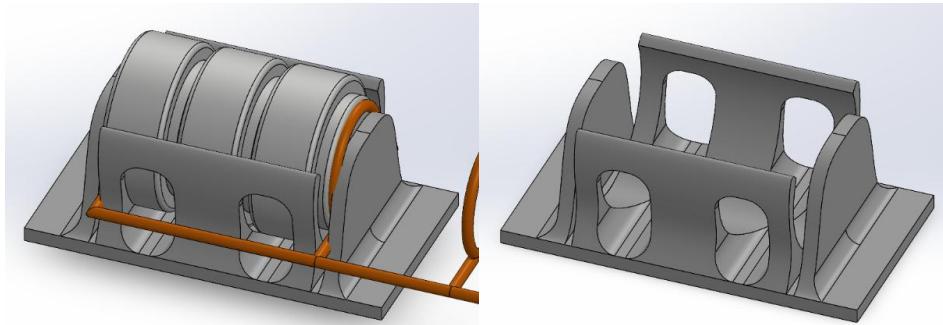


Figure 10: Image of Battery Holders with and without components

Included in the housing are two battery holders designed to contain a set of three Zi-Air 675 Cells in series. These allow a user to snap in and out batteries for deployment while holding the batteries in place and pressing them against the wire connected to the PCB's power lines. The walls surrounding the batteries are 0.75mm thick, the inner diameter of the walls is equivalent to the outer diameter of the Zi-Air Cells, and the walls rise 25° above the horizontal midplane. The end walls are 1mm thick and are spaced 0.5mm away from the ends of the series of batteries to provide room for the power line wires to contact the batteries.

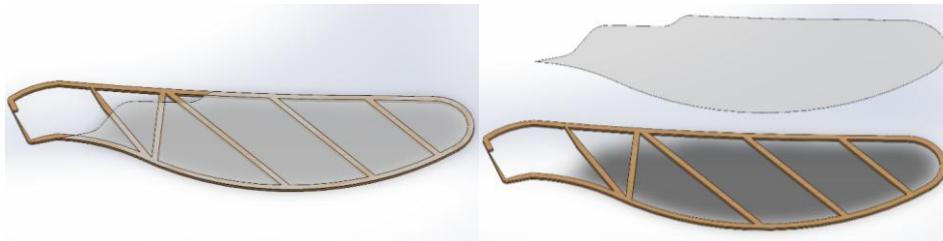


Figure 11: Images of wing assembly with and without skin

The wing of the payload is comprised of a laser cut birch wood skeleton with a visqueen polyethylene plastic sheeting to span the empty space in the wing. Team FireSense chose to laser cut the wing skeleton for the payload because it afforded a similar degree of customizability and rapid manufacturability in design. We selected birch wood to laser cut because it is an easy-to-use hardwood, readily available, and produces consistent results when laser cut. The wing skeleton has an overall dimension of 479.58mm by 157.73 by the birch wood stock thickness of 1/8in, following the contour of the nut housing as well as the contour of a typical samara leaf sound in nature. There are struts along the length of the wing every 71.68mm to provide rigidity to the wing. The width of the cutout parts is 6.35mm in all places, and the thickness of the birch wood is 1/8in.

The wing skin was applied with a hot glue to bond with the birch wood skeleton and cut to the outer edges of the skeleton. The full assembly was sealed in the same manner to provide a functioning prototype for drop testing.

DESIGN EVALUATION

Electronics Design

Filter Testing

Testing the filter was divided into multiple stages, accounting for more subdivisions of the design in each experiment, starting from the output to the dev board. Each stage was validated individually with an oscilloscope and an arbitrary waveform generator, the latter programmed according to the transient simulations from the designing phase of the project. Foremost, tests were conducted directly on the filter, with and without the inverting amplification; the oscilloscope was connected to read the voltage level on the development board's pin, and the waveform generator was connected to represent the output of the pre-amplification circuit following microphone on the schematic (Appendix.) Readings from the oscilloscope were compared to the SPICE simulations to validate the filtering capabilities, programming only two points per decade for ease of testing. Afterward, the experimental scope was expanded to include the pre-amplification circuit, substituting the microphone with the arbitrary waveform generator and proceeding as previously. Filter behaviors were considered functional if they were “reasonably proportional to” the simulated results as simulations were conducted under significantly different conditions. Smaller, irregular signals from the microphone, unique layout capacitances and inconsistent variations in the values of passive components were, at this scale, inclined to disrupt results. Example oscilloscope readings are shown below:

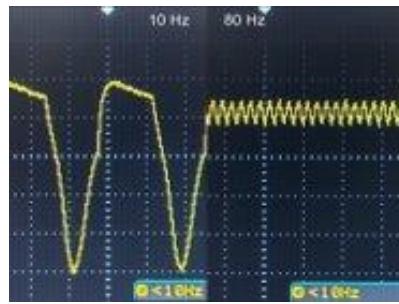


Figure 12: Attenuation, less than -7 dB from 10Hz to 80Hz

DePaolis expected attenuation at this frequency to be sharper than -20 dB, or less than 1% of the input amplitude. While inconclusive, this result demonstrated that the filter was properly attenuating higher frequencies, or more specifically, showed expected behavior.

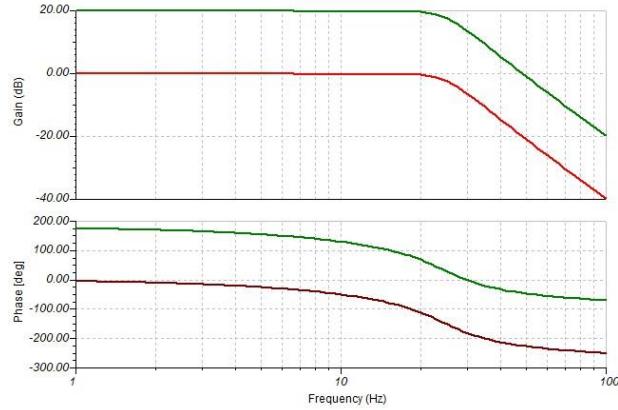


Figure 13: Simulated, perfect attenuation results from filter (in appendix)

Size Reduction

Shipp made multiple PCB layout optimizations to reduce the overall size of the electronics system. DePaolis ensured that the reconfigurations, changes in track weights, and reduced component sizes did not compromise any of the PCB connections via simple inspections with multimeters. Since the schematics were pre-simulated in SPICE, a nodal analysis was employed to find node voltages, and some noteworthy node voltages like the filter power rails were compared. Power connections were verified with LEDs on specific components on the board.

Payload Design/Delivery

Salcido and Woods determined that physical prototyping would save time and be inexpensive. The team was concerned with proving the scalability of the wing because the governing principles behind the Samara leaf design seemed to suggest that a samara leaf of any size would fly a desired flight profile so long as the weight distribution is correctly placed. Since the density of air was not going to change from testing small models to the large ones, it was just as feasible that the wings would not fly in the desired manner once scaled to be too large.

1/5 Scale Model Testing

Woods designed four wing shapes to evaluate their flight characteristics at 1/5 scale the size of the expected full assembly. Each shape was skinned with yellow tissue paper and were designed to fit a universal nut printed from PLA. The models were taken to a 14ft balcony on the South side of the University of Idaho IRIC building and dropped in cloudy conditions, gusting at 5 mph. Shape A (Appendix) was modeled by designing over a picture of a natural samara leaf. Since this shape was the most found in nature, the other wings were adjusted to come off this original shape. Shape A's flight characteristics were the most inherently neutral regarding its dart-mode flight time and its rotational stability. Shape B (Appendix) featured a more emphasized droop designed to catch more air as the leaf fell. Drop tests of Shape B successfully demonstrated

that a large wing surface area would encourage both the rotational flight phase and the coverage of more distance as the wing would stay airborne for longer. Shape C (Appendix) fell straight down in the lateral axis with minimal spinning, as did Shape D (Appendix) which spun flat but fell fast. Shape A's most neutral and reliable flight characteristics were achieved by attaching a small lead fishing wight to wing spar closest to the nut with a piece of tape.



Figure 14: Samara Shapes (left to right) A, B, C, and D

1/2 Scale Model Testing

Shape A was scaled up to 1/2 the size of the predicted full-scale model and taken to the 3rd floor of the Atrium in the University of Idaho IRIC building, 32ft above the ground. The 1/2 scale model was dropped several times as Salcido and Woods recorded the flight characteristics and experimented with the effects of weight distribution by attaching small fishing weights to distinct areas of the design. The most neutral flight characteristics were achieved when fishing weights were taped to the inside of the nut. Video footage was taken of each drop test in slow-motion to create stills for rotation angle estimation and velocity calculation. The 1/2 scale Samara model reliably fell with a fall angle of 6°, started spinning after falling 5ft, and its calculated fall velocity was 1.78m/s.



Figure 15: Display of Samara ½ scale with space to insert lead weights

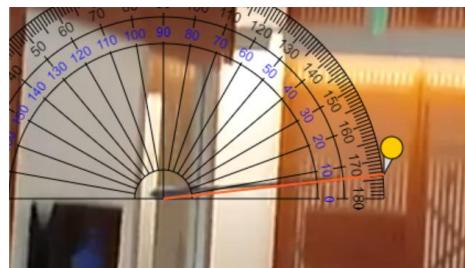


Figure 16: Fall angle Approximation of ½ Scale Model

Commented [S(1): @Depaolis, David (depa8396@vandals.uidaho.edu)] My browser won't download to work in the desktop app right now, can you please add a caption to this image to fit the others to say "Samara Shape C"?

Full Scale Model Testing

Full Scale Model drop testing took place at the University of Idaho atrium in the same fashion as the 1/2 scale model, testing the validity of the weight distribution practices learned for the half-scale model. A new wing nut was designed for the full-scale PCB, and it featured a larger wing area. No fall angle data was recorded because the design failed to autorotate due to what was believed to be incorrect weight distribution. Woods recreated the 1/2 scale model shape to fit the SMT PCB and drop testing yielded favorable results. The heavier payload fell at 29.3°, started spinning after falling approximately 14ft, and fell at a terminal velocity of 1.83m/s.

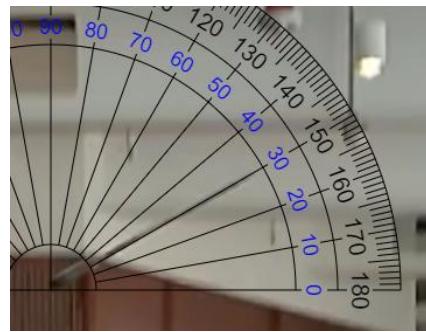


Figure 17: Fall Angle Approximation of Full-Scale Model

FUTURE WORK

Electronics

Possible directions for future teams regarding the electronics system are listed below.

The following teams should aim to further reduce the size of the PCB by using a bare chip (ESP32) design and outsourcing a finalized board layout to a commercial manufacturer. This will lead to a smaller and lighter electronics system, which in turn would lead to a smaller payload delivery device. This endeavor will take another year of research and manufacturing; however, it is crucial to the reduction in price and size of the sensor.

Signal acquisition, identification, and interpretation testing needs to be performed. Past teams did not find adequate time to evaluate and record the performance of the microphone and filter combination. Tests and Analysis should be performed to determine the range and accuracy (finetune ~20 Hz target) of the microphone, as well as test the accuracy of the microphone and filter combination. This investigation should take half a semester, and the cost should be near zero.

In the far future, combining the knowledge of the sensor accuracy and the flight characteristics of the payload, teams should be able to optimize the density (number of sensors/area) of Infrasonic Wildfire Detection devices needed to accurately scan the area being monitored. This should consider the size of the area, as well as the number of obstacles present

Commented [D(2): Remember to put any good suggestions from EXPO here

and their size. This endeavor should take a year of development, once other aspects of the project are completed, and should have near to zero cost.

During engineering EXPO, one attendee suggested implementing a sonic sensor for game tracking/migration patterns. This would take a year's worth of work for proper integration, and the cost should remain small.

Payload Design

Possible directions for future teams regarding the payload design are listed below.

Investigate how changing the form and weighting of the samara payload affects its flight characteristics. Future teams can characterize what different physical properties have on the flight; examples may include does a thicker leading-edge lead to a faster transition to autorotation, how does weighting placement affect the flight characteristics? The investigation into characterizing these effects would take one to two more years of research and development, however, it would not cost much as the supplies to manufacture a single full sized payload cost around \$2-3.

Research materials for weatherproofing and sealing and implement a procedure for sealing the payload. Team FireSense used a 3M Hot Meld Adhesive Glue to seal the payload together. Future teams should investigate a watertight sealant and create a procedure for application that covers all points of liquid ingress. Special consideration should be made for the possibility of moisture wicking into the payload through the wood wing skeleton. This should only take a semester of research and application, with the cost staying just above the price of sealants.

Future teams should investigate the feasibility of creating a 3D wing skeleton? If the time to produce a wing shape is still efficient, this could make the wing portion of the payload thinner and lighter. FireSense experimented with Loctite plastic bonder to permanently join separate 3D printed parts. Research from Wind Dispersal of Natural and Biomimetic Maple Samaras paper stated a 30:1 nut-to-wing weight ratio was “heuristically providing the desired autorotation properties.”

Further research should be made into environmentally friendly materials to reduce any adverse effects that might stem from leaving the payload out in nature. Teams should consider the interaction between the payload and its components with the local flora and fauna. This research should take a year and would cost only the price of the materials used to manufacture new payloads.

APPENDICES

Calculations and Drawings

Material Selection

Book Reference: Materials Selection in Mechanical Design by Michael F. Ashby 5th Edition

Integration of Material Selection Index referencing techniques from Materials Selection in Mechanical Design by Michael F. Ashby

$$M = \frac{\sigma^2}{\theta}$$

Figure 7: Strength over Density calculation

Parachute Information

https://www.webpages.uidaho.edu/dl2/on_target/tv.htm

$$D = \frac{1}{2} \cdot A_p \cdot \rho \cdot V^2$$

Drag Equation

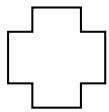


Figure 1 Cross Parachute



Figure 2 Square Parachute

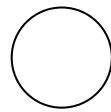


Figure 3 Circle Parachute

Autorotation Information

https://www.faasafety.gov/gslac/alc/course_content_popup.aspx?cID=104&sID=452#:~:text=Autorotation%20is%20the%20state%20of,event%20of%20an%20engine%20failure.

Low Flying Aircraft Information

https://www.faa.gov/about/office_org/field_offices/fsdo/lgb/local_more/media/FAA_Guide_to_Low-Flying_Aircraft.pdf

Samara Wing Shapes

Figure 9 Samara Shape
A



Figure 8 Samara Shape
B



Figure 10 Samara Shape
D

Figure 11 Samara Shape C



Figure 12 Samara 1/5 Scale marked with A and 1/2 scale without marking.

Payload Drop Testing Calculations

Slow-Motion video was taken on a Samsung Galaxy A71 phone camera that displays video at 1/5 the speed of regular video.

1/2 Scale Model:

Rotation Angle= 6 degrees

The item fell for 30 slow-motion seconds= 6 seconds

23 seconds slow-motion, 4.6s falling in rotation

Object Height= 32 feet- 9.7536 meters

Object Rotation Height= 27 feet= 8.2 m

Rotation Falling Velocity= 1.78 m/s

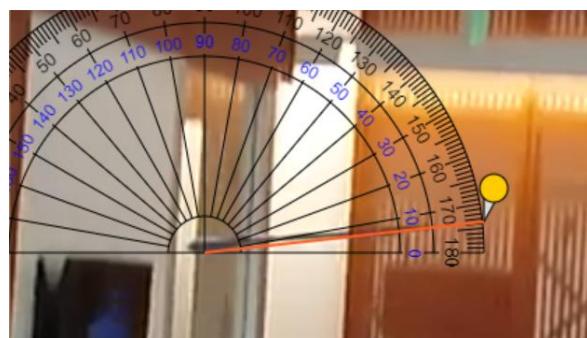


Figure 13: 1/2 Scale Samara Fall Angle Approximation- 6°

Full Scale Model

Time to Fall: In Slow-motion (4 seconds) in x2 Samsung Galaxy S10e camera (Actual 2 Seconds)

Fall Distance spinning: 12'= 3.66m

Fall spin Velocity= 1.83 m/s

Rotation Angle: 29.3°

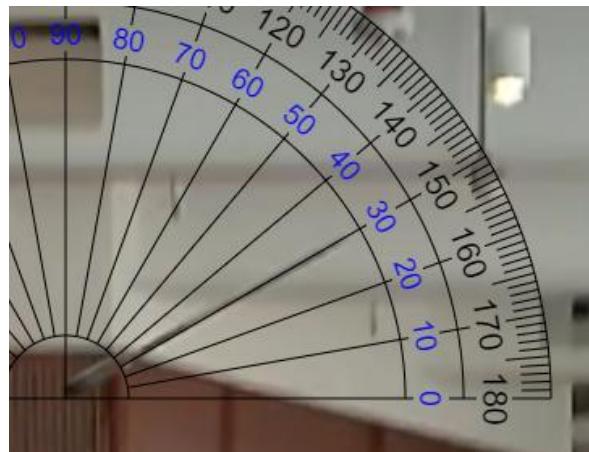


Figure 14 Samara Full Scale Fall Angle Approximation

Payload Assembly Drawing Package

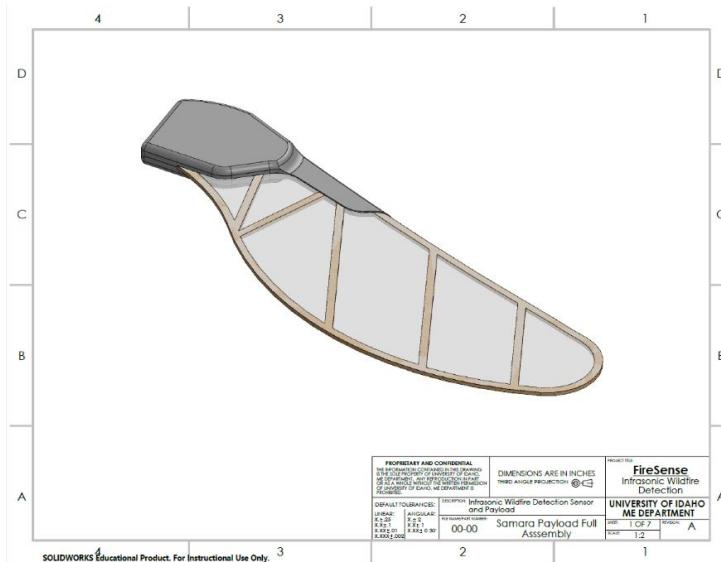


Figure 15: Technical Drawing Package Sheet 1, Full Assembly

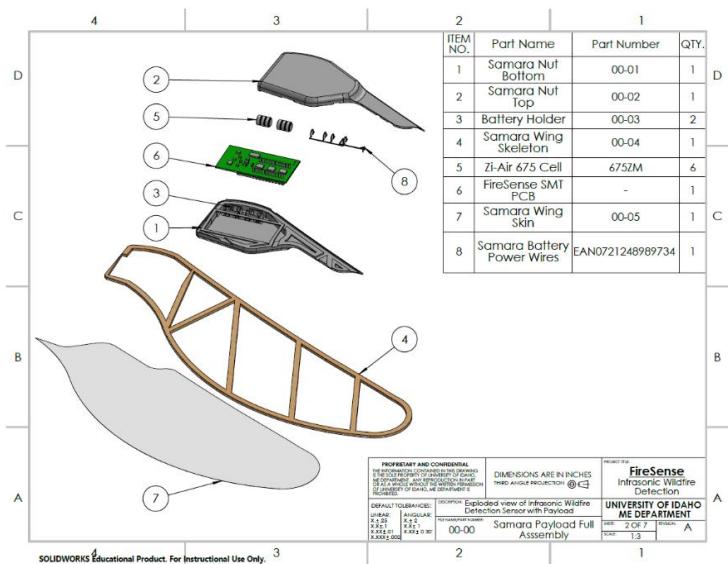


Figure 16: Technical Drawing Package Sheet 2, Exploded View

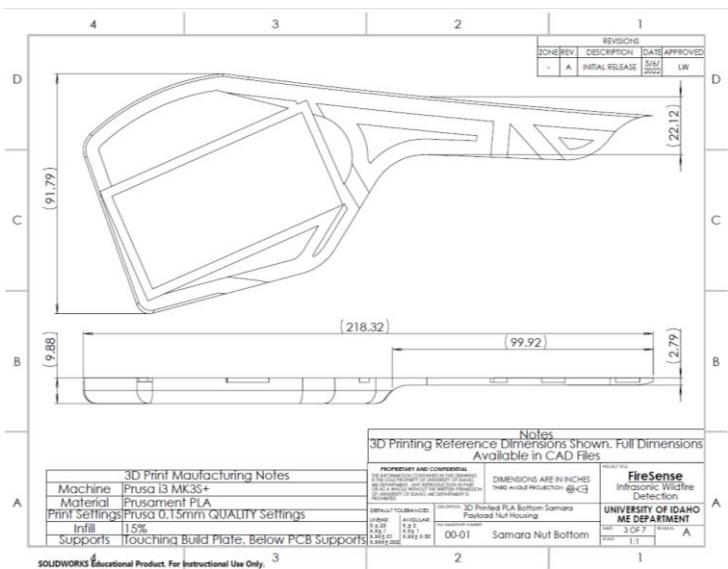


Figure 17: Technical Drawing Package Sheet 3, Samara Nut Bottom

INFRASONIC WILDFIRE DETECTION

24

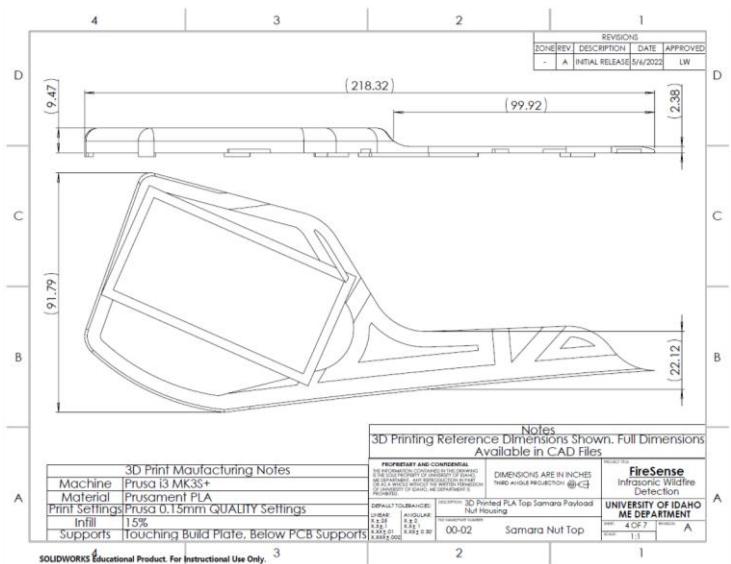


Figure 18: Technical Drawing Package Sheet 4, Samara Nut Top

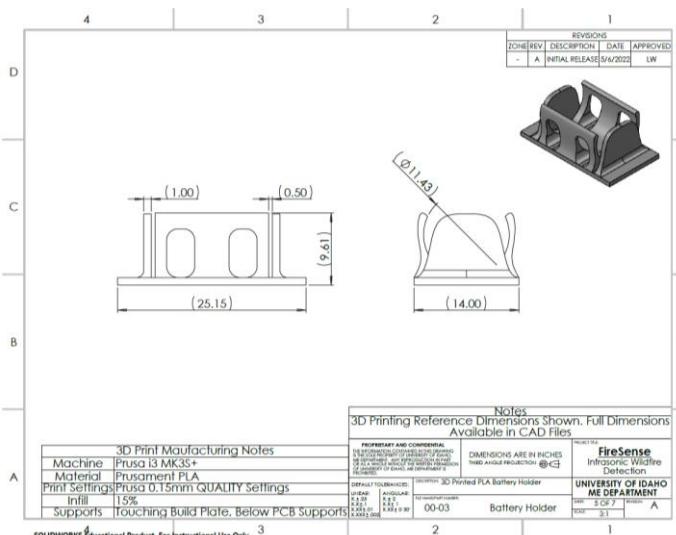


Figure 19: Technical Drawing Package Sheet 5, Battery Holder

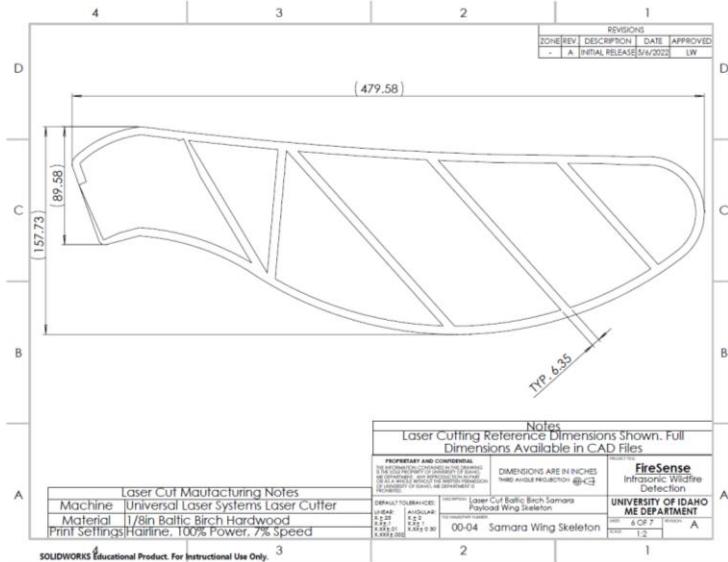


Figure 20: Technical Drawing Package Sheet 6, Samara Wing Skeleton

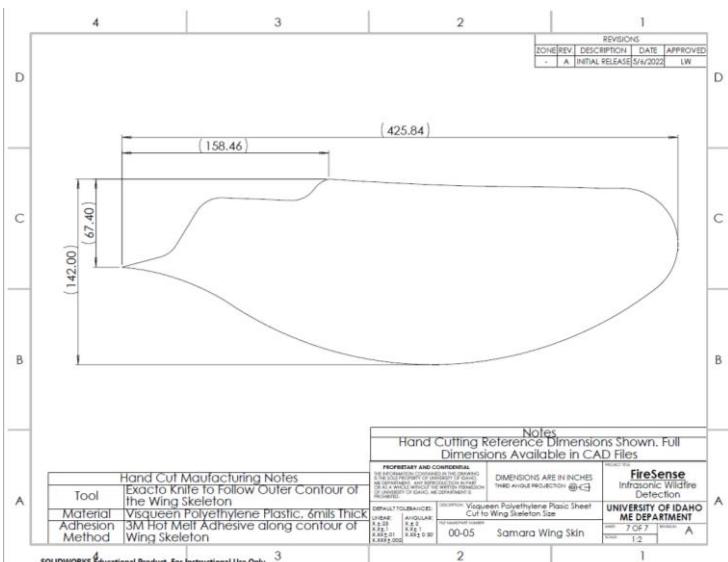
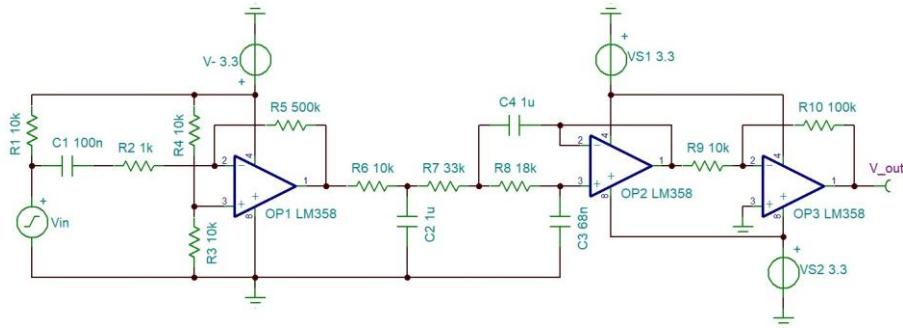
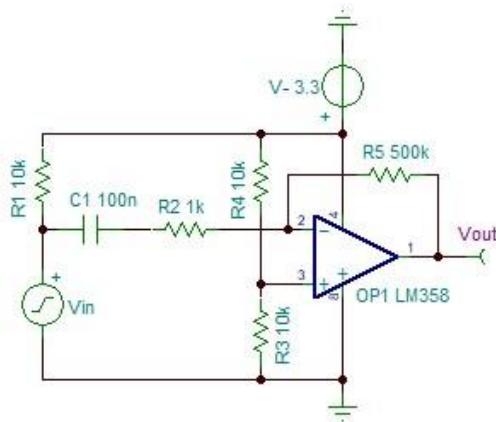


Figure 21: Technical Drawing Package Sheet 7, Samara Wing Skin

Large Tables and Figures

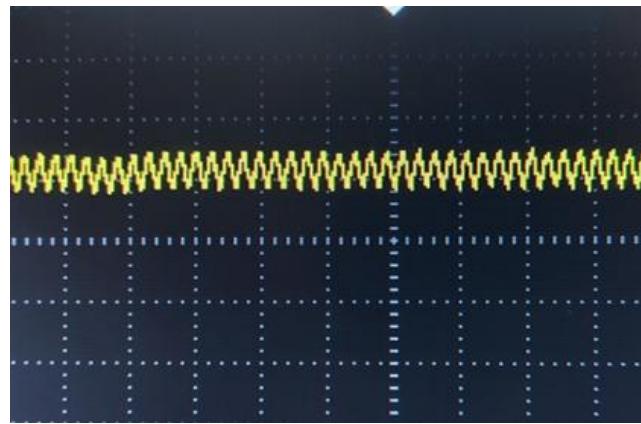
Full low-pass (Sallen-Key topology) filter circuit, modified from previous team's work



Pre-amplification circuit, microphone represented by source Vin



Microphone filter output, sinusoidal input at 10 Hz



Microphone filter output, sinusoidal input at 80 Hz

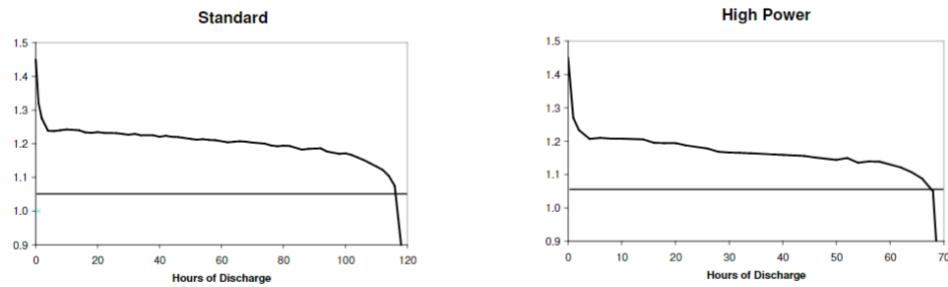


Figure : Typical Discharge Performance of Zi-Air Cell

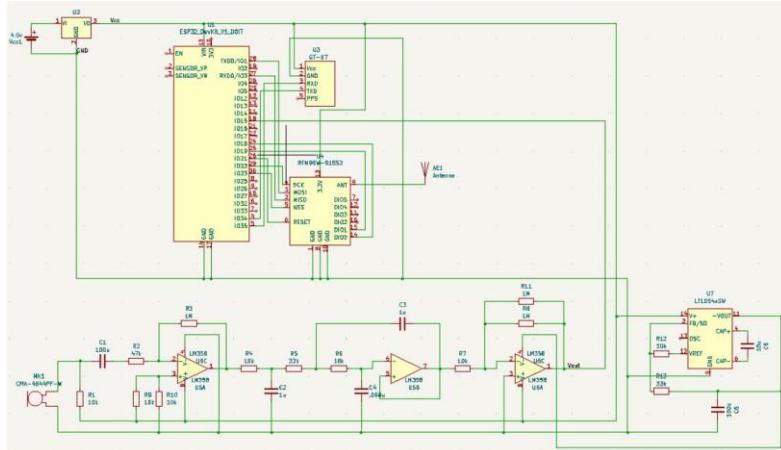


Figure 22: PCB Schematic

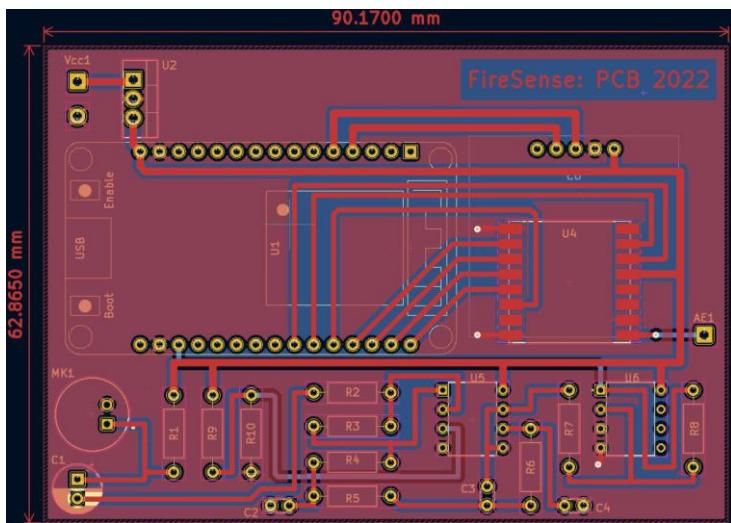


Figure 23: PCB_v1: THT Components

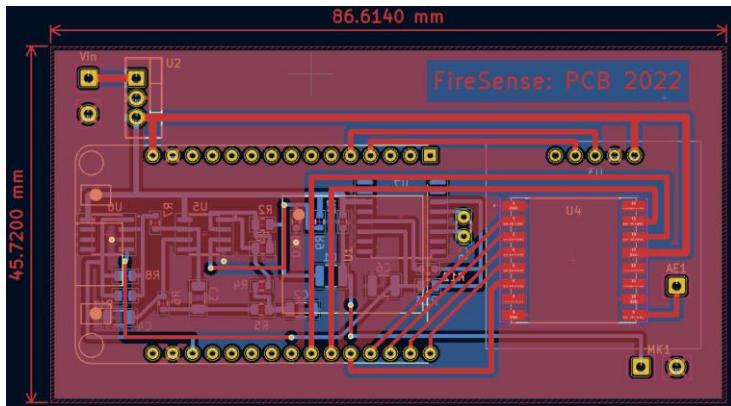


Figure 24: PCB_v2: SMT Components

Component	# per PCB	Total Cost (\$)
Voltage Regulator (TC1262)	1	0.93
Dev Board (ESP32)	1	7.3
GPS (GT-U7)	1	9.5
Transceiver (RMF95W)	1	5.6
Microphone (CMA-4544PF)	1	0.66
Op-Amp (LM358)	2	0.4
Voltage Inverter (LT1054)	1	2.44
Zi-Air Battery (675ZM)	6	1.85
Cap (0.068uF)	1	0.36
Cap (1.0uF)	2	0.56
Cap (10.0uF)	1	0.43
Cap (100.0uF)	2	0.78
Res (10k)	6	0.56
Res (18k)	1	0.09
Res (33k)	2	0.16
Res (47k)	1	0.08
Res (1M)	3	0.24
PCB 2022:	31.94	
PCB 2021:	50 (Estimated Average)	
Cost Reduction:	$(\$50.00 - \$31.94) / \$50.00 = \underline{\text{36.12 \% Cheaper}}$	

Figure 25: PCB Cost Breakdown

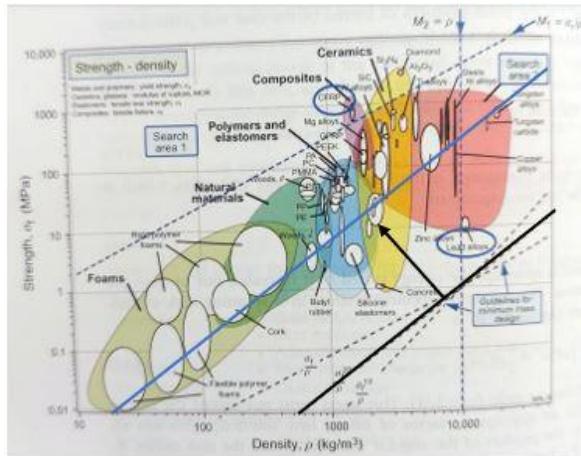


Figure 26: Materials Selection Table

Computer Programs

KiCad EDA – Schematic Capture & PCB Design Software (v6.0)
TINA-TI v9 (9.3.200.277 SF-TI)

Prusa Slicer 2.4.1

SOLIDWORKS 2021

Vendor Data Sheets

Active Electrical Components

[ESP32](#)

[ESP32 Development Board](#)

[LM358](#)

[Transceiver](#)

[GT-U7](#)

[Batteries](#)

Passive Electrical Components

[Thin Film Resistors](#)

[KEMET Tantalum SMT Capacitors](#)

[Kyocera AVX Tantalum SMT Capacitors](#)

Commented [D(3): The vendor data sheets is only for the major components like the GPS, opamps, etc?

Commented [WL(4R3): No, add vendor sheets for everything you bought. This needs to be comprehensive

[Plusivo 24AWG Hook Up Wire Kit](#)**The Plusivo Hook up Assorted Wire Kit includes:**

- Black AWG 24 Tinned Copper Silicone Wire (30 ft)
- Red AWG 24 Tinned Copper Silicone Wire (30 ft)
- Yellow AWG 24 Tinned Copper Silicone Wire (30 ft)
- Green AWG 24 Tinned Copper Silicone Wire (30 ft)
- Blue AWG 24 Tinned Copper Silicone Wire (30 ft)
- White AWG 24 Tinned Copper Silicone Wire (30 ft)
- Heatshrink Tubes
- Colored Wire Ties Mini Wire Stripper Tool



Tinned Copper Core

The benefits of having tinned copper wire include protection against corrosion, ease of soldering, and providing the same conductivity as bare copper.

Uniformly Coated with Silicone

The uniform insulation makes the wire easy to strip and cut. The Silicone insulation provides high flexibility, resistance to acids, oils, alkalies, moisture, and fungus, and offers good abrasion resistance.

Comes with these Additional Items

The kit includes a set of heat shrink tubes, a mini wire stripper tool, and colored wire ties, which may be used for other everyday projects.

**Hook-Up Wire Kit****24 AWG Stranded Core**

Stranded Core Hook-up Wires are more flexible than solid core wire of equal size, making them perfect for wiring circuits on frequently moving parts like robot arms.

Kit Includes:

- 6 x hook-up wire rolls (black, white, red, blue, green, yellow)
- 60 x wire ties / 10 per color (black, white, red, blue, green, yellow)
- 1 x heat shrink tube set (black, red, yellow)
- 1 x mini wire stripper



Plusivo Hook-Up Wires are assorted in colors for easy identification and color coding. The wires are contained in a box casing to keep your workspace organized. Items included are mini wire stripper, heat shrink tubes, and wire ties.

Conductor Size / Number	24 AWG / 40 pcs	Conductor Resistance	91.6 Ω/km
Strand Diameter	0.08 mm	Rated Voltage	600 V
Insulation Thickness/Material	0.2 mm/Silicone	Rated Temperature	200 degrees C
Conductor Diameter / Material	0.58 mm / Tinned Copper	Packaging	6 different colored 29 Feet spools
Outer Diameter	1.6 mm	Applications	Model airplanes, RC toys, Remote Control, Electronic, Battery Cable, drones, DIY, etc

Don't delay. Buy today.

Clear Gorilla Glue

APPLICATION TEMPERATURE – 32° to 100° F, best at room temperature

SERVICE TEMPERATURE – -20° to 180° F

OUTDOOR – Yes

MOISTURE RESISTANT – Water resistant – not recommended for continual water exposure

PAINTABLE – Yes – Can be painted with oil-based and spray, acrylic/latex and stains require sanding

SANDABLE – Yes

STAINABLE – Yes – Will require sanding

EXPANDS WHEN CURED – No

CURED COLOR – Clear

TECHNICAL STANDARDS – ANSI/HPVA Type II

STORAGE TIPS – Store in a cool, dry location. Store with access to light, if possible.

GAP FILLING – Minimal

Material Datasheets



Figure 27: Technical Datasheet Prusament PLA Sheet 1

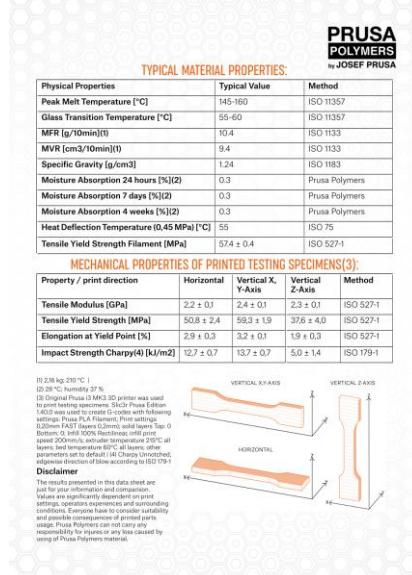


Figure 28: Technical Datasheet Prusament PLA Sheet 2

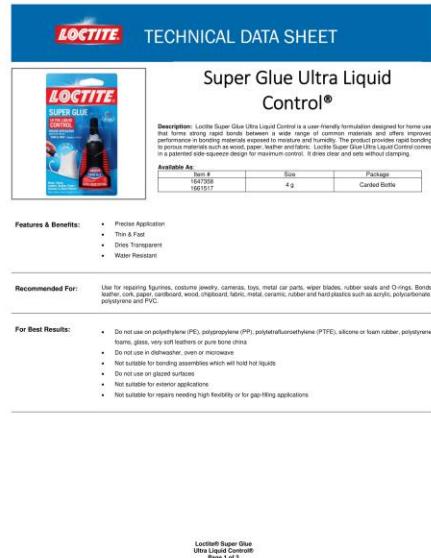


Figure 29: Technical Datasheet Loctite Super Glue Sheet 1



Figure 30: Technical Datasheet Loctite Super Glue Sheet 2

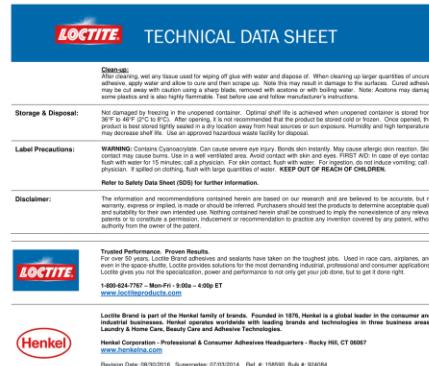


Figure 31: Technical Datasheet Loctite Super Glue Sheet I

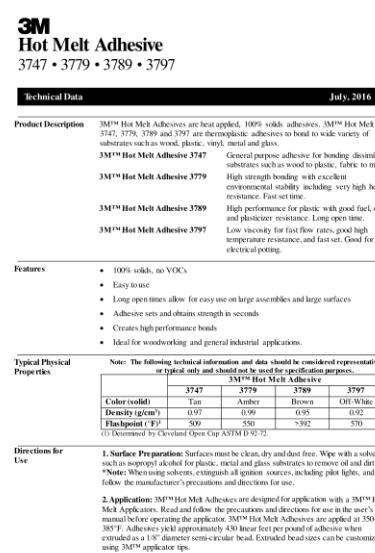


Figure 32: Technical Datasheet 3m Hot Melt Adhesive Sheet 1

3M™ Hot Melt Adhesive
 3747 • 3779 • 3789 • 3797

Directions for Use (continued)

3. Coverage: 3M™ Hot Melt Adhesive yields approximately 430 linear feet per pound of adhesive when extruded as a 1/8" diameter semi-circular bead.

4. Set up time: After the bond is made, 3M™ Hot Melt Adhesives immediately build strength and no clamping is necessary. Set will occur faster on cold or metallic substrates.

Typical Application Properties

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.				
3M™ Hot Melt Adhesive				
3747	3779	3789	3797	
Application Temperature ¹	150°F/63°C	185°F/85°C	185°F/85°C	185°F/85°C
Viscosity (CPS) ²	4,100 cP 375°F	7,000 cP 375°F	5,200 cP 375°F	2,650 cP 375°F
Open Time (seconds) ³	45	25	50	30
Delivery Time (seconds) ⁴	45	75	70	55
Available sizes/forms	5/8"x8' Q 5/8"x8' TC 1" x 70' PG 1" x 70' Bulk 1/8" Bulk	5/8"x8' Q 5/8"x8' TC 1" x 70' PG 1" x 70' Bulk	5/8"x8' Q 5/8"x8' TC 1" x 70' PG 1" x 70' Bulk	5/8"x8' TC 1" x 70' PG

(1) Recommended application temperature range. Temperature can be adjusted to regular desired viscosity/delivery and post-life.

(2) Determined at 100 rpm shear rate in Cetriscope using a #27 Spindle @ 10 RPM.

(3) Open time is the maximum time between the application of the adhesive and when the parts must be joined together. Data based on 1/8" semi-circular bead on one metallic substrate at 75°F.

Higher temperatures will shorten open time; larger beads will lengthen open time.

(4) Extrusion time for one 1" x 70' PU cartridge.

Typical Performance Properties

Note: The following technical information and data should be considered representative or typical only and should not be used for specification purposes.				
3M™ Hot Melt Adhesive				
3747	3779	3789	3797	
Heat Resistance ⁵	145°F/63°C	300°F/140°C	220°F/104°C	170°F/77°C
Ball & Ring Melt Point ⁶	220°F/104°C	325°F/163°C	230°F/132°C	340°F/151°C
Shear Strength ⁷	430 psi	700 psi	570	350 psi
Pest Strength ⁸	20 psi	18 psi	16 psi	10 psi
UL544 Testing	90	90	V2	V2
FDA Indirect Food Contact ⁹	21 CFR 175.105	21 CFR 175.105	21 CFR 175.105	21 CFR 175.105

(5) Direct temperature that the adhesive will support a 2% peel load.

(6) ASTM D-2857 Test Method.

(7) Overlap shear measured on Douglas Flite to Douglas Flite.

(8) Measured in pounds per inch width (psi). Flexible carnauba bonded to Douglas Fir.

(9) Permitted for indirect food contact (subject to the limitations in applicable CFR sections).

Figure 33: Technical Datasheet 3m Hot Melt Adhesive Sheet 2

3M™ Hot Melt Adhesive
 3747 • 3779 • 3789 • 3797

Storage Store product below 120°F (49°C).

Shelf Life When stored at the recommended conditions, this product has a shelf life of 2 years after 3M ships the product to a customer or distributor.

Precautionary Information Refer to Product Label and Material Safety Data Sheet for Health and safety information before using this product. For additional health and safety information, call 1-800-364-3577 (651) 737-6501.

Product Use All statements, technical or otherwise, contained in this document are based upon tests or experience that 3M believes are reliable. However, many factors beyond 3M's control can affect the actual performance of its products in a particular application. Therefore, it is the responsibility of the user to test the product to determine whether it is fit for a particular purpose and suitable for use. 3M makes no warranties, expressed or implied, regarding the performance of its products. For a detailed statement of 3M's warranty obligations, refer to the 3M Terms and Conditions of Sale at www.3m.com/industrial.

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3M
 Industrial Adhesives and Tapes Division
 3M Center, P.O. Box 33-3506
 St. Paul, MN 55144-3506
 800-363-3556 • 877-369-2921 (Fax)
www.3m.com/industrial

2009-0109

Figure 34: Technical Datasheet 3m Hot Melt Adhesive Sheet 3

Project Schedule

Infrasonic Wildfire Detection

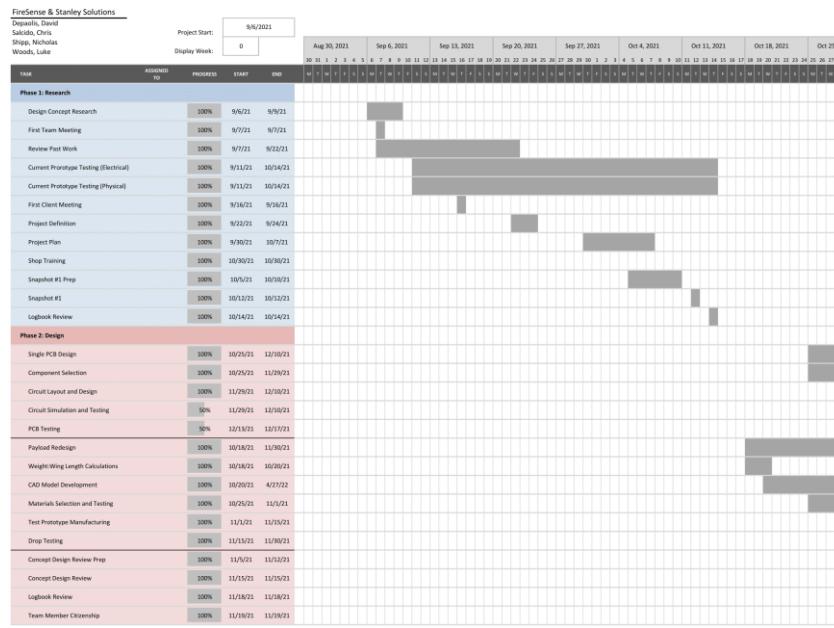


Figure 35: Team FireSense Gantt Chart, First Half of Tasks Sheet 1

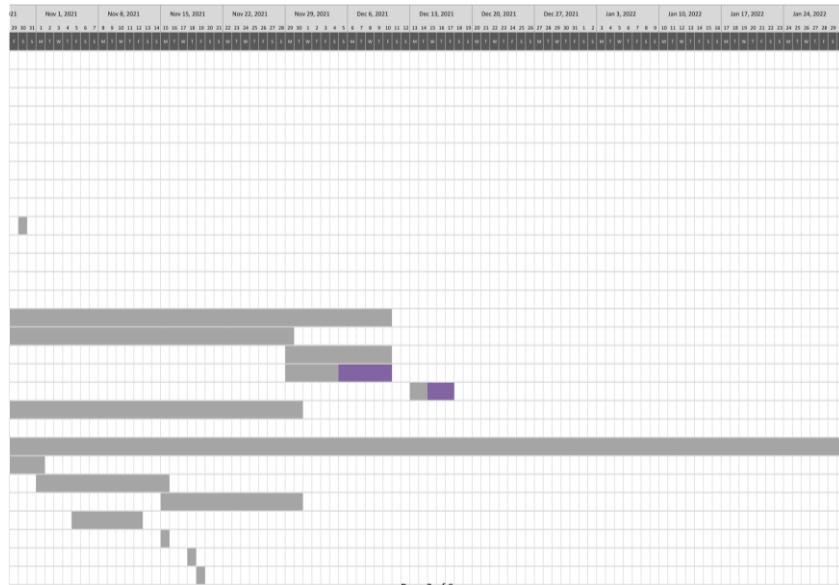


Figure 36: Team FireSense Gantt Chart, First Half of Tasks Sheet 2



Figure 37: Team FireSense Gantt Chart, First Half of Tasks Sheet 3

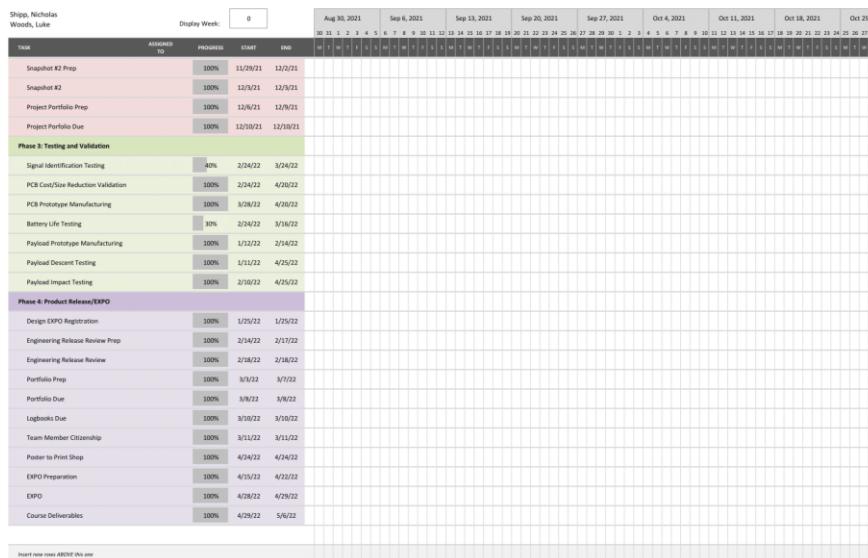


Figure 38: Team FireSense Gantt Chart, Second Half of Tasks Sheet 1

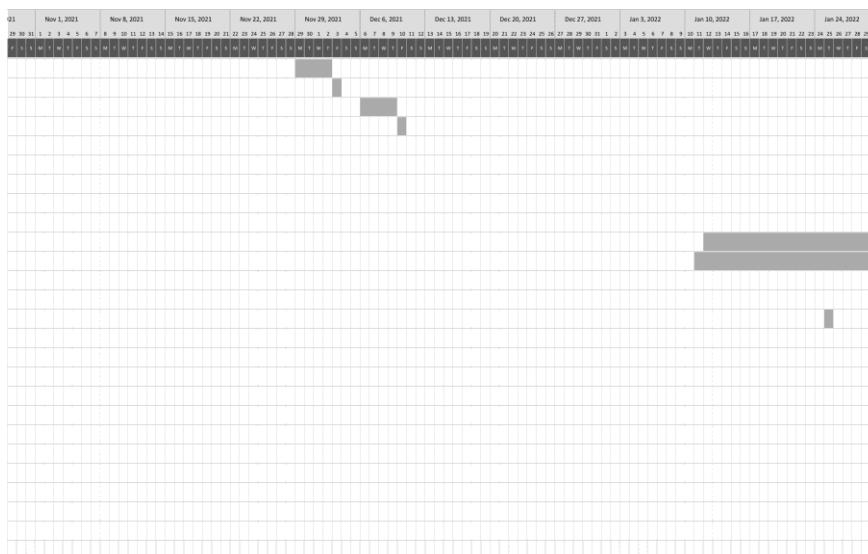


Figure 39: Team FireSense Gantt Chart, Second Half of Tasks Sheet 2

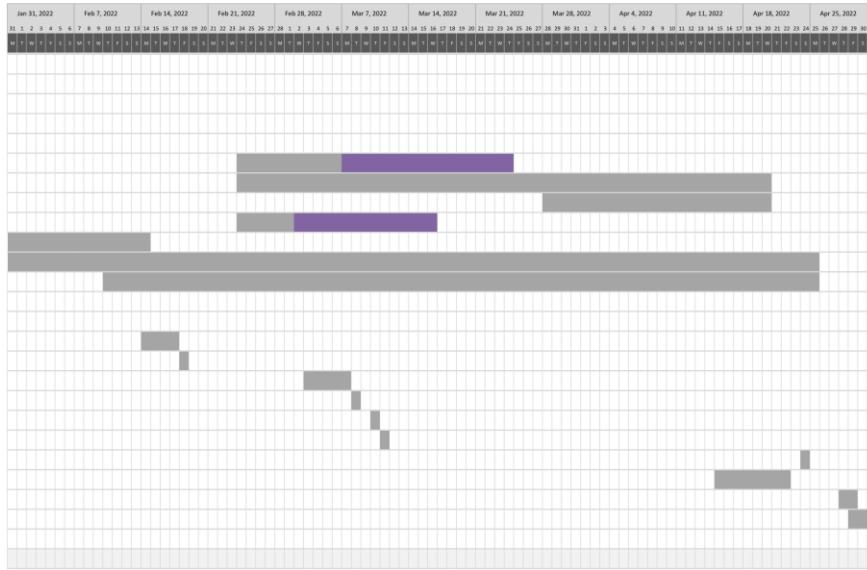


Figure 40: Team FireSense Gantt Chart, Second Half of Tasks Sheet 3

DFMEA Worksheet

System	Potential Failure Mode and Effects Analysis (Design FMEA)										FMEA Number
Subsystem	Prepared By Luke Woods										
Component	FMEA Date 5/6/2022										
Design Lead	Revision Date										Page 1 of 1
Core Team											
Component	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	S ev	Potential Cause(s)/ Mechanism(s) of Failure	P rob	Current Design Controls	D et	R P N	Recommended Action(s)	Responsibility & Target Completion Date
Low-pass Filter	Attenuate input signals with frequencies above ~20 Hz	Component package corrosion	Failure to filter microphone input	6	Exposure to environmental humidity	6		3	108	Components with thermal tolerance and sealing	
Printed Circuit Board	Condense interconnections between devices in payload	Dust deposition, waterlogging, and other environmental on board	Short circuits, passive component damage	5	Passive environmental effects	5		4	100	Sealing for payload capsule and a solder mask	
GPS Unit	Provide location data for the mesh network establishment	Maximum digital I/O current exceeded	Damaged pin I/O disables node in network	3	Environmental shorting traces	5		6	90	Sealing for payload capsule and a solder mask	
Printed Circuit Board	Condense interconnections between devices in payload	Scratches, environmental and/or flux corrosion on traces	Open circuits, power loss, false readings	6	Handling by operator or manufacturer, exposure	5		3	90	Implement a solder mask, change copper weight	
Low-pass Filter	Attenuate input signals with frequencies above ~20 Hz	Solder joint failure	Poor electrical connection or open circuits	5	Thermal stresses, manufacturing defects, or	3		4	60	Implement sealing and overspec solder	
Radio Transceiver	Provide communications capabilities (LoRa module) required in the mesh network	Electrical damage in package	Malfunctioning node and mesh network break	3	ESD from handling	3		6	54	Professional manufacturing, protection on board for future bare-chip designs	
Microphone	Provide means to collect data from environment	Diaphragm, electret material and packaging thermal degradation	Reduced sensitivity and range	3	Exceptionally warm temps in specific environments with direct sunlight	2		7	42	Include warning for operator	
Microphone	Provide means to collect data from environment	Degraded solder joints	Reduction or complete loss of input signal	5	Cyclical thermal stresses from environment	4		2	40	Stress test prototype, Redesign PCB to permit micro replacement	
Voltage Regulator	Control the input battery voltage for the power rails on the PCB	Excess torque / mechanical damage in through-holes	Copper foil damaged / pulled away from board	6	Handling by operator or payload delivery	3		2	36	Solder mask and placement on board with clearance	

Figure 41: DFMEA Analysis of IWD Electronics Sheet 1

Figure 42: DFMEA Analysis of IWD Electronics Sheet 2

Figure 43: DFMEA Analysis of IWD Samara Payload Body Sheet 1

Component	Item / Function	Potential Failure Mode(s)	Potential Effect(s) of Failure	Severity	Potential Cause(s)/Mechanism(s) of Failure	P r e v e n t	Current Design Controls	D e t	R P N	Recommended Action(s)	Responsibility & Target Completion Date	Action Results				
												Actions Taken	New Sc.	New Oz.	New Det.	New RP.
Wing Skin	Produce lift during flight by lining the wing skeleton.	Skin improperly attached to Wing	Wing may fall faster than safe parameters for the samara body.	6	Adhesive improper bonds, insufficient adhesive along skeleton,	4	Visual inspection, press test on wing skin sections	2	48	Test bonding agents that don't weaken over time or after impact. Create adhesive application tool for assembling the wing						
Wing Skeleton	Provide the wing shape, structural support for the wing skin, and contribute to	Fracture during impact.	Wing may not be reusable during testing.	3	High Impact Force.	4	Visual Inspection	2	24	Select a tougher wood or find a stronger material that doesn't increase the payload's						
Wing Skin	Produce lift during flight by lining the wing skeleton.	Skin tears upon landing.	Wing may not be reusable during testing.	3	Abrasion or tearing due to warping of wing skeleton during impact	3	Wing skin currently made of visqueen, a light, durable plastic. Visual inspection and	2	18	Select wing materials that are abrasion resistant and light. Design instruction						

Figure 44: DFMEA Analysis of IWD Samara Payload Body Sheet 2

File Organization

1. Problem Definition

Contains Problem Statement, Value Proposition, and Product Requirements documents.

2. Project Learning

Contains Snapshot 1 resources, initial research, and example videos of maple seed drops.

3. Project Management

Contains Administrative Resources, Team Budget, and Meeting Minutes (as well as meeting presentations and images).

4. Design Solution

Contains Design Review 2 and Snapshot 3 resources, Payload CAD files, and PCB components.

5. Implementation and Manufacturing

Contains PCB prototype guidelines as well as PCB design files for all versions.

6. Design Validation

Contains Design Review 2 and Snapshot 3 resources, as well as scale model drop testing.

7. Final Design Documentation

Contains Final Report, Final Presentation, and Engineering EXPO Resources (poster, slideshow).

8. Videos

Contains final assembly drop testing videos, and the laser cutting process.